

# Curvature Control of Silicon Microlens for THz Dielectric Antenna

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**Abstract**—We have controlled the curvature of silicon microlens by changing the amount of photoresist in order to microfabricate hemispherical silicon microlens which can improve the directivity and reduce substrate mode losses.

## I. INTRODUCTION AND BACKGROUND

Our group has recently proposed a concept of stacking multiple silicon wafers in order to build a large format terahertz heterodyne array for both ground based and space applications [1, 2]. However, metallic horn antennas are not suitable for such silicon based array implementation due to size and mass. New silicon antenna technology is necessary in order to couple the RF signal on top of the silicon stacked array. Thus, the use of silicon microlens has been proposed and proven as an antenna solution [3-5]. One of the key advantages is to microfabricate silicon microlens antenna arrays on a single silicon wafer by a single microfabrication process, e.g. over 100 x 100 silicon antenna arrays. However, in the previous paper [5], we were only able to microfabricate a small upper portion of the hemispherical microlens even though hemispherical microlens could improve the directivity and reduce substrate mode losses of a dielectric antenna [6].

In this paper, we have controlled the curvature of the silicon microlens in order to microfabricate a hemispherical microlens by changing the amount of photoresist among other process parameters including etching selectivity between photoresist and silicon.

## II. MICROFABRICATION

First, a silicon wafer was prepared, coated with photoresist, and patterned as shown in Figure 1. Secondly, the photoresist is reflowed on a hot-plate. When the temperature is above the glass transition temperature ( $T_g$ ), the photoresist forms photoresist microlens due to surface tension. Thirdly, we have etched both the photoresist and silicon simultaneously in order to transfer the shape of the photoresist onto the silicon using a Reactive Ion Etching (RIE) process. Lastly, the photoresist was completely etched away to complete the transfer. In order to produce a microlens with the desired geometrical properties, such as height, and radius of the curvature, we could utilize two process parameters such as etching selectivity (photoresist versus silicon) and the amount of initial photoresist. Since we transfer the shape of photoresist onto the silicon wafer using a RIE etching process, both initial height and radius of the curvature of the reflowed photoresist directly affect the silicon microlens. For example, if we reflow

photoresist patterns of different thicknesses with the same size of diameter, thicker photoresist will have a taller and higher curvature of the photoresist microlens. Since the photoresist microlens has a higher curvature and height, the silicon microlens will have a higher curvature and height when they're transferred onto the silicon wafers with the same etching recipe. Thus, both the curvature and height of the silicon microlens can be controlled by the initial amount of photoresist which determines the height and curvature of photoresist microlens. The diameter of microlens is determined by the mask layout.

In addition to the initial amount of patterned photoresist, the etching selectivity between photoresist and silicon could control both the height and curvature of silicon microlens. For example, if the etch rates of silicon and photoresist are the same (in other words, the etching selectivity is 1:1), the exact shape of photoresist will be transferred onto a silicon wafer. However, when the etch rate of the silicon is 2 times faster than that of the photoresist, the curvature of silicon microlens will be increased by a factor of 2. Conversely, if the etch rate of silicon is 2 times slower, the curvature will be reduced by half.

In this paper, we only have changed the initial thickness of the photoresist in order to change both the height and curvature of the silicon microlens.

## III. RESULTS

Figure 2 shows a circular silicon microlens array on a 4 inch silicon wafer. The diameter of the silicon microlens is approximately 1mm. There are over fifty 10x10 silicon microlens arrays (over 5,000 microlenses) on a single silicon wafer. Figure 3 shows the Scanning Electron Microscope (SEM) images of a silicon microlens array. As you can see in the SEM image, the surface is very smooth with its surface roughness less than 1  $\mu\text{m}$  based on the surface profiler measurement.

Figure 4 shows the surface profile of microlenses with different thicknesses. We have prepared 3 photoresist samples with different thicknesses: 30  $\mu\text{m}$ , 47  $\mu\text{m}$ , and 60  $\mu\text{m}$ . After thermal reflow, the height of the photoresist microlens became 45  $\mu\text{m}$ , 68  $\mu\text{m}$ , and 95  $\mu\text{m}$ , respectively. During height measurement, there was a few micron error caused by inability to scan the center of the microlens with a surface profiler. As shown in Figure 4, both the height and curvature could be controlled by the initial thickness of the photoresist. We have

measured 3 to 4 microlenses with the same size on different locations in order to check the uniformity. Figure 5 shows different height of the silicon microlens with different diameter.

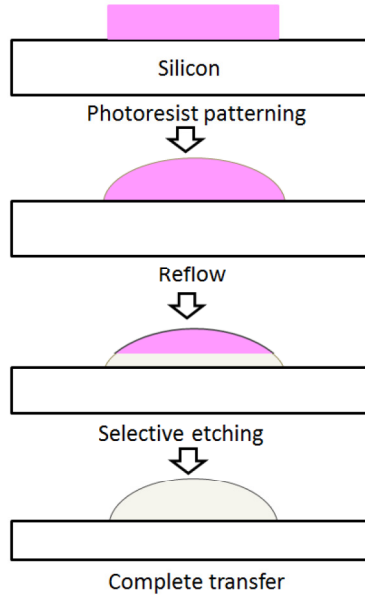


Figure 1. Schematic diagram of microfabrication of a silicon microlens array.

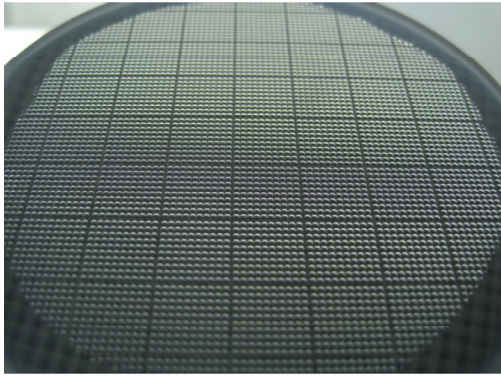


Figure 2. A photograph of reactive-ion-etched silicon microlens array. The diameter is approximately 1mm.

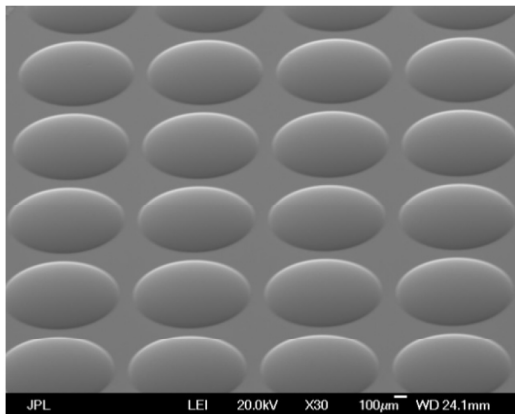


Figure 3. A SEM image of the silicon microlens array. Microlens with a diameter of 1 mm and height of 53  $\mu\text{m}$ . Shown is a very smooth surface.

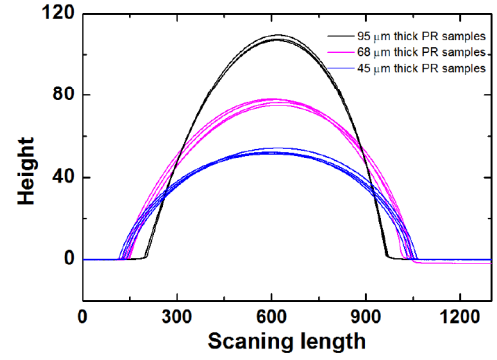


Figure 4. Surface profile of silicon microlenses with different heights.

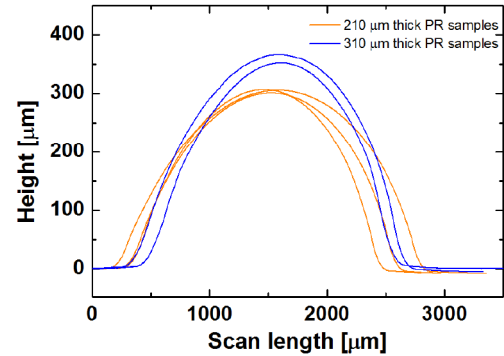


Figure 5. Silicon microlenses with different heights and diameters.

#### IV. CONCLUSION

We have controlled both the height and curvature of the silicon microlens of which diameter ranges from 1 mm to 2.5 mm with different initial photoresist thicknesses. The shape of the silicon microlens was uniform throughout the entire wafer, and the surface was very smooth.

#### ACKNOWLEDGMENT

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